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HIGH PERFORMANCE MODULES BASED ON BACK CONTACTED SOLAR CELLS

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ABSTRACT: In this work the latest results considering the developments of rear contacted cell structures and their interconnection is presented. For this work the metallisation wrap through structure (MWT) has been selected as preferred rear contact cell structure because of its potential to be introduced in a cost effective industrial cell production line. A stable cell process for MWT-cells has allowed the production of sufficient 10x10cm^2 multi-crystalline cells to construct a large area module with a peak power of 54W$_p$. Next to this high peak power, in this module a planar interconnection of all series connected cells is demonstrated. The latest developments of MWT cells with minimal front surface shading allowed the demonstration of average cell efficiencies of 15.4% in an 8 cell mini-module. Because of the reduced front surface shading of the cells, the modules based on back contacted solar cells are distinguished by their high current density and uniform visual appearance. This is underlined by the construction of an "all black" crystalline silicon module.
KEYWORDS: PV module - 1: Back Contact - 2: Building Integration - 3

1. INTRODUCTION

The development of rear contacted solar cells was driven by a triple objective: improving the cell performance, reducing module assembly cost and improving the visual appeal of photovoltaic products.

All three objectives are required in order to simplify access of photovoltaic products into the market of building integration, the fastest growing market segment for this renewable energy source. While this application offers large potential to contribute significantly to the power supply within industrialised and densely populated regions of the world, PV systems are only hesitantly accepted not only because of cost and cost-effectiveness, but also because of aesthetics.

The first objective can be realised by reducing the shading losses and increasing the collection volume within the base of the cell. Secondly, having the external contacts on the rear surface allows for the development of a planar interconnection technology that allows a simplification of the automation in the module assembly and corresponding increases in assembly yield. Finally, removal of a major part of the front surface metallisation in combination with isotropic etching allows constructing modules with a very uniform outlook. Furthermore, when carefully designed, it is a practical solution for the realisation of artistic contact patterns [1] as the functional interconnection on the rear surface is not affected by the actual shape of the front surface metallisation.

2. BACK CONTACTED SOLAR CELLS

2.1. Cell structures

The main feature of the back contact cell structures is the displacement of the visual disturbing part of the external contacts of the front surface grid to the rear surface.

The best known rear contacted cell structures are probably **the rear junction solar cells** such as the point contact solar cells developed at Stanford University [2] and commercialised by Sunpower Corporation [3]. The absence of any front surface metallisation in combination with the high material quality used and excellent front surface passivation resulted in the demonstration of 1-sun cell efficiencies well over 20%. However, it can be shown that the material quality and surface passivation not only help in achieving top efficiencies, but furthermore form a prerequisite for the application of this structure [4]. Simulations show that in order to obtain efficiencies over 15% based on this cell structure with moderate quality materials such as multi-crystalline or even CZ-wafers (L_n=100-300μm), the substrate thickness should be reduced to below 100μm and the front surface recombination velocity kept below 100cm/s. As substrates with this thickness are not readily available on the market, the industrial introduction of rear contacted solar cells depends on the development of cell structures that do not rely on the high material quality needed for back junction solar cells.

The first step in this direction was the development of the **emitter wrap through** solar cell [5,6]. In this cell structure, a collecting junction is maintained at the front surface and the collected current is guided to the external contact at the rear of the cell by extending the emitter in the walls of numerous openings through the substrate. The appearance of this structure in industrial production line is impeded by a technological barrier. In order to limit the power losses related to current flowing through the relatively high resistive emitter, a vast amount of openings through the wafer (typically 100 holes/cm^2) is required. In spite of efforts by several institutes worldwide, no technology has been identified by which this huge number of holes can be realised at the throughput of a modern solar cell production line.

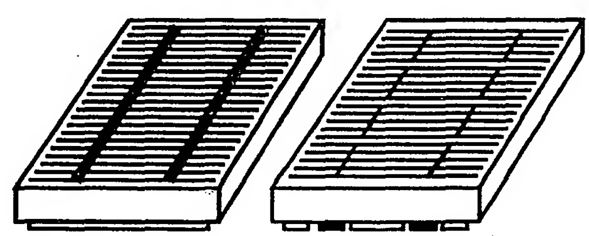

FIGURE 1
Impression of the visual change of a solar cell by moving only the bus bars to the rear surface

In contrast to the first two cell types, in both the **metallisation wrap through (MWT)** and **metallisation wrap around (MWA)** structures, some of the metallisation on the front surface is maintained. Compared to a typical conventional bulk crystalline silicon solar cell, only the bus bars are moved to the rear surface. Both structures maintain the same functionality as the EWT cell, but with a minimal number or even without holes. In the MWT approach, a conductive connection through the wafer is foreseen between the remaining fingers on the front surface and the bus bars at the rear surface at the locations of their crossing. Further reduction of the number of holes can be achieved by maintaining some minor bus bar parts, guiding the current of several fingers to one hole as illustrated in figure 1. In the MWA approach the connection between the fingers and the rear surface bus bars is realised around the edge of the wafers [7]. This means the current needs to flow from all over the cell area to the edges of the wafers. This can result in increased levels of resistive losses even in the presence of a metallic grid on the front surface. Therefore, the attention for the remainder of this paper is directed to the metallisation wrap through structure, which in principle has no limits to its scalability.

2.2. Processing of back contacted solar cells

The developments towards a screen printing based process for metallisation wrap through, metallisation wrap around and emitter wrap through cells [8], has resulted in a controllable and reproducible process for rear contacted solar cells. The process flow is depicted in figure 2 and compared to a screen printing based process flow for conventional solar cells. It starts with the creation of the required openings in the wafers. After exploring different options, the laser technology was evaluated as best suited to fulfill this task. The formation of the openings is followed by an acidic etch for the combination of texturing and the removal of the damaged layer (both from the hole formation as the saw damage). After a $POCl_3$ diffusion, an ARC (SiN_x) is deposited and a double screen-printing step (front and rear surface) is executed for the emitter contact metallisation. Subsequently, the rear surface base contact is screen-printed and both contacts are co-fired.

The separation of the different polarity regions on the rear surface of the cells remains the major processing problem for these rear contacted cell structures. In our processing, either a dry plasma etch is used in which the rear surface metal grids are used as self-aligned masks or the formation of the parasitic junction is avoided by a diffusion mask [9].

In view of the metallisation wrap through structure, there are some specific technological challenges. In order to keep the process flow as close as possible to the conventional processing, the realisation of a reliable through hole interconnection of metal grids on opposite surfaces of the cell should be realised by screen printing from both surfaces. This can be assured by combining the pushing of the paste during the printing step with sucking the paste through the hole. The latter can be done by means of custom designed print tables that combine a vacuum to hold the wafer in place with a vacuum that is aimed at creating an under-pressure under the holes through the wafers. Another challenge is posed by the need of an adequate formation of the emitter within the walls of the holes. This can be obtained by application of a gas phase diffusion such as from a $POCl_3$-source.

As can be seen on figure 2, the new cell structure requires only two additional processing steps compared to the conventional screen printing based cell process: the formation of the openings and the screen printing of external emitter contacts on the rear surface.

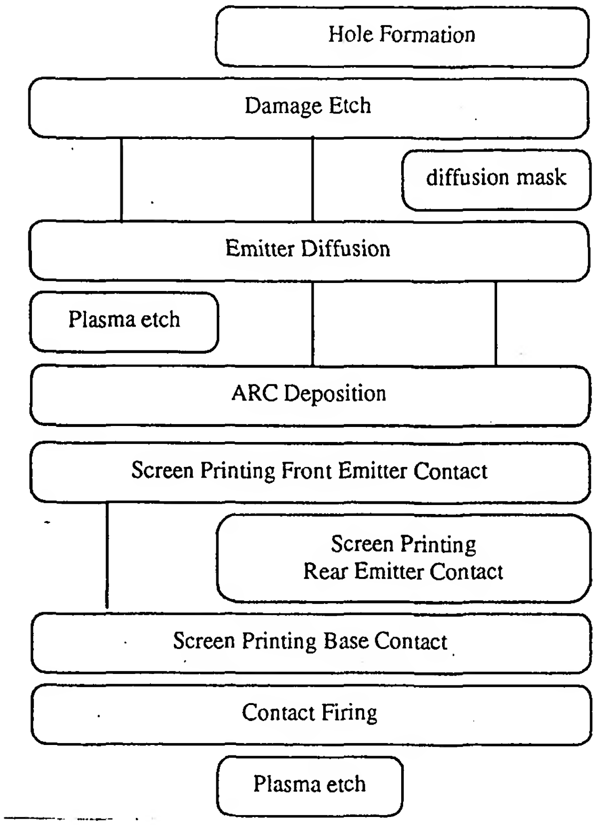

FIGURE 2
Comparison between the screen printing based process flow for conventional and rear contacted cell structures

With the availability of a functional cell process, the step towards optimisation can be made. From this optimisation phase it is expected that the demonstrated gain in current through the reduced shading losses [8] can be translated in a proportional gain in efficiency and that cells can be demonstrated competing in performance with the best cell results published for industrial type solar cells. At this stage, the process allows to produce sufficient cells in order to assemble demonstration modules and to support the start of the development of a fully planar interconnection technology.

3. BACK CONTACTED MODULES

3.1. Interconnection technology

The rear surface patterns on the cells that were processed according to the established process combine the application of a large surface coverage of aluminium and its related advantages [10] with the presence of solderable contact dots.

In figure 3, the stringing process applied for the prototype module based on MWT solar cells is schematically represented. The first steps in the stringing

process consist of soldering a series of parallel interconnection tabs to both external polarity contacts, with the opposite polarities extending on either side of the cell. Because the rear surface metal patterns that have been used were not optimised towards simplification of the interconnection technology, additionally an isolation patch has to be formed on top of the non-extending extreme of the emitter connection tab. This isolation patch makes it possible to make a transversal interconnection of the four base contact tabs. Finally, the cells are shifted as close as possible together and the extensions of the emitter interconnection strips of one cell are soldered to the transversal strip that was formed in the previous step, thus establishing the series interconnection of the cells. After stringing the cells, they were embedded in Ethyl Vinyl Acetate (EVA) and encapsulated in between glass at the front surface and white tedlar at the rear surface.

At first sight, the applied procedure to realise the required strings seems rather complicated. However, a demonstration was given of the possible planar interconnection that was aimed for at the start of the developments of the rear contacted cell structures as all interconnections can be performed without flipping any of the cells.

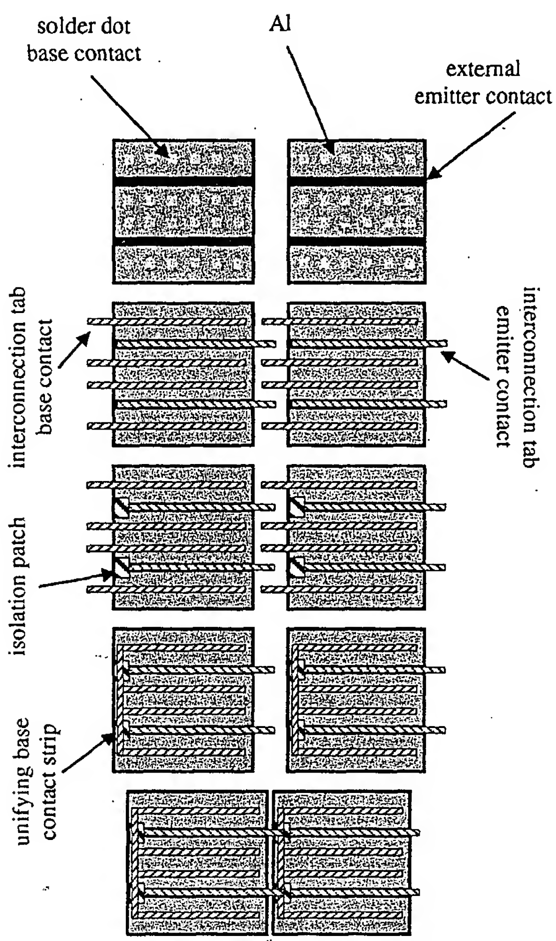

FIGURE 3
Schematic representation of the stringing process applied for the prototype module based on metallisation wrap through solar cells

Simplification of the process flow is expected as building up the interconnection paths in several steps on individual cells as described above can be replaced by depositing this path for a complete module as pre-formed contacts. This will allow automation of the cell stringing in a pick-and-place approach and open the road towards the integrated realisation of modules [11].

3.2. Module results

Next to the planar interconnection, the demonstration of highly efficient devices was one of the main objectives of this work. The result of the electrical characterisation of an experimental 36 cells module is represented in table I, together with the derived parameters of an 'average cell'. These parameters are calculated assuming 36 identical devices in the module. As a reproducible cell efficiency of 15% could be demonstrated, which is mainly due to the high value of the current density. The resulting $54W_p$ module is not only the highest reported performance for a large area module based on rear contacted cells but furthermore it outperforms most similar sized industrially manufactured conventional modules.

Table I: Performance of 36 MWT cells module and derived efficiency of average cell performance in the module (Baysix multi-c, $10x10\ cm^2$)

	Isc *Jsc*	Voc	FF (%)	Pmax *Eff.*
Module	3.44 A	21.9 V	71.5	53.9 W_p
Average Cell	*34.4 mA/cm²*	608 mV		*15.0 %*

The third anchor addressed by the developments of rear contacted solar cells is harder to quantify. Only with time an indication can be expected whether the quest for improved aesthetics has resulted in satisfying results. However, from the pictures of both a conventional module and the experimental counterpart represented in figure 4, the potential of improved uniformity can clearly be seen.

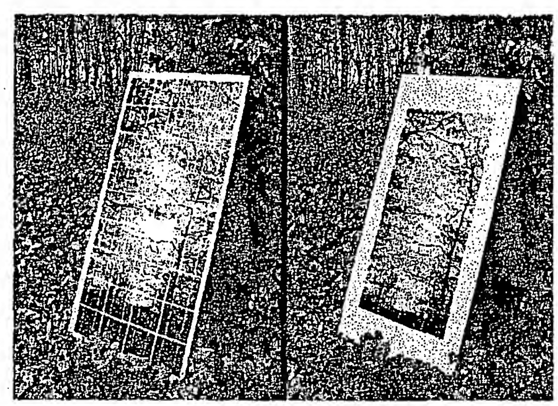

FIGURE 4
Picture of a conventional (left) and a rear contact module (right) indicating the aesthetic difference between the photovoltaic devices

The most striking feature of the demonstration module is its uniform appearance when seen from a distance.

Nevertheless with the first generation MWT cells reminiscents of the bus bars on the front can still be experienced as disturbing when viewed from a closer distance. This observation combined with the slight increase of series resistance that has lead to the low fill factors, makes the development of MWT cells with every finger individually connected to the rear surface a logical next step in the development of rear contacted cell structures and modules [9]. Next to a number of non-functional 8-cell prototypes illustrating the unique visual appearance for crystalline silicon cell modules (see figure 5), the full potential of the new structures was demonstrated. In table II the electrical characterisation of an 8-cell MWT module is shown.

Table II: Performance of 8 MWT cells module and derived efficiency of average cell performance in the module (Polix multi-c, 10.1x10.1 cm^2)

	Isc *Jsc*	Voc	FF (%)	Pmax *Eff.*
Module	3.37 A	4.9 V	76.3	12.6 W_p
Average Cell	*33.0 mA/cm²*	613 mV		*15.4 %*

For this module, the cells are produced with a rear surface diffusion mask. The obtained current density shows an increase of 4.5% compared to co-processed reference cells while there is no difference in open circuit voltage. As a result the cell efficiency measured after encapsulation also shows an increase of 4% relative [9]. The high fill factor of the mini-module indicates there is no problem with the cell processing or the applied interconnection strategy.

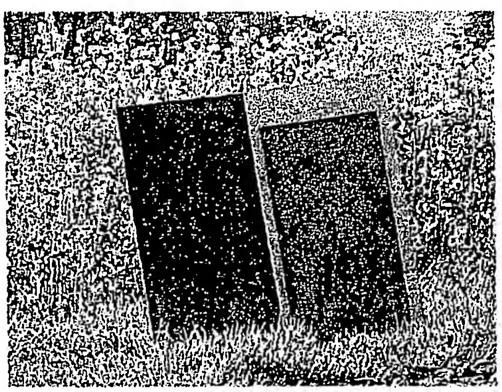

FIGURE 5
Modules based on rear contacted solar cells show a very uniform appearance and the possibility to realise "black modules'

4. CONCLUSIONS

In this paper the current status is described for the three objectives behind the development of rear contacted solar cells. Thanks to the increased cell efficiency, several high performance modules were realised demonstrating the principle of planar interconnection. Because of the high packing density that was applied, these modules do not only show a high peak performance but furthermore, the module efficiency comes very close to the cell efficiency.

Aesthetics are very hard to capture in numbers. We believe however that the demonstration of the very uniform outlook for the MWT-based modules resulting in an "all black" crystalline silicon module can assist the marketing for building integration of photovoltaic energy.

5. ACKNOWLEDGEMENT

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